SCRAAM – AN EXPERIMENT TO TEST REACTOR FLUX PREDICTIONS AND PROBE THE "REACTOR ANTINEUTRINO ANOMALY"

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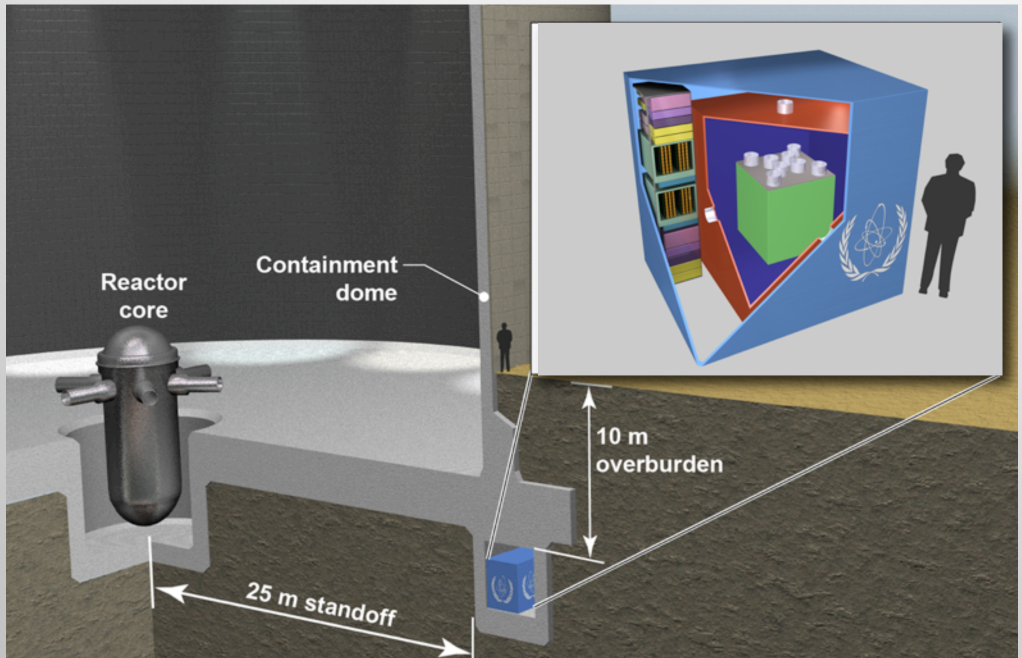
There is increasing interest in (Short Baseline) Antineutrino Monitoring of Reactors




IAEA
International Atomic Energy Agency
Atoms for Peace

Final Report:
Focused Workshop on Antineutrino Detection for Safeguards Applications

28-30 October 2008
IAEA Headquarters, Vienna

AAP
2011

IAEA
International Atomic Energy Agency
Atoms for Peace

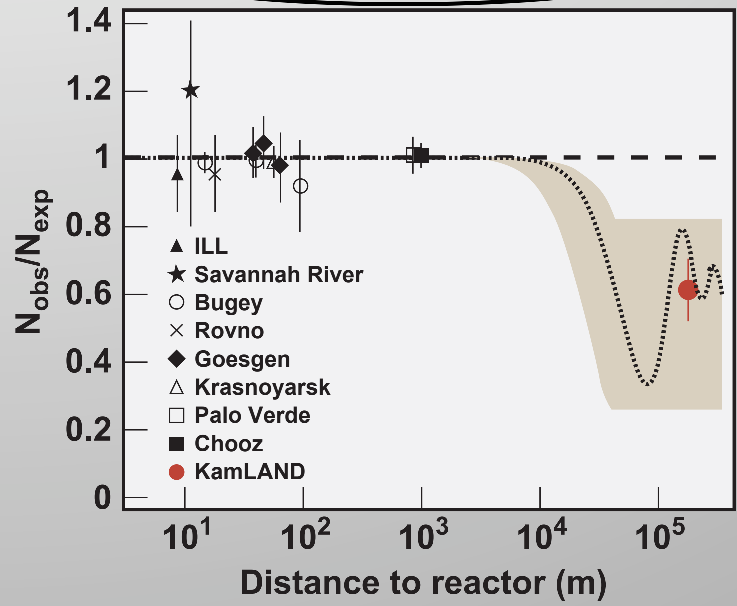
AGENDA

Ad Hoc Working Group on Safeguards Applications of Antineutrino Detectors, 14 September 2011, Vienna, Austria

Basic science laid the foundation for this monitoring technique

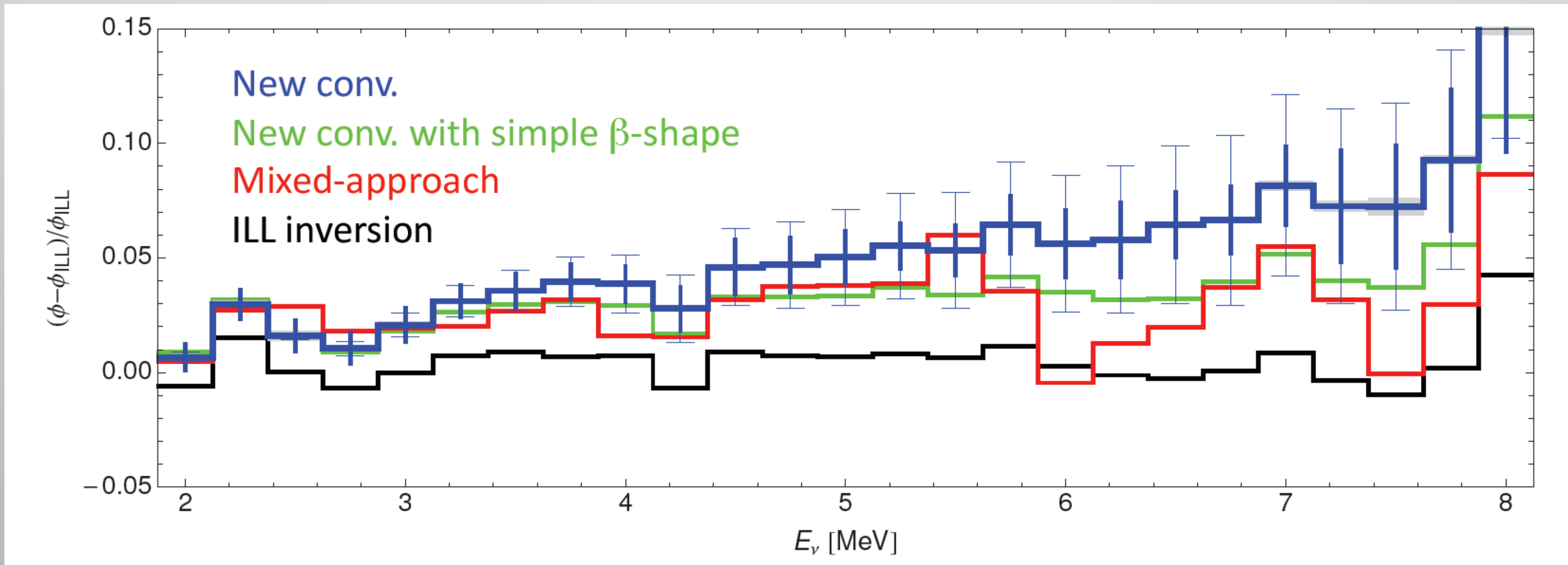
- Reines and Cowan, 1956:
  - First to detect antineutrinos using a reactor source and a liquid scintillator detector

- Three decades of neutrino oscillation studies have provided:
  - ~~A mature technology base~~
  - A quantitative understanding of reactors as an antineutrino source ?



Recent Re-evaluations of the Reactor Antineutrino Flux

- We have seen strong efforts to improve the conversion of ILL reference spectra to antineutrino spectra: ~3% increase in flux
- Two largely independent predictions agree:



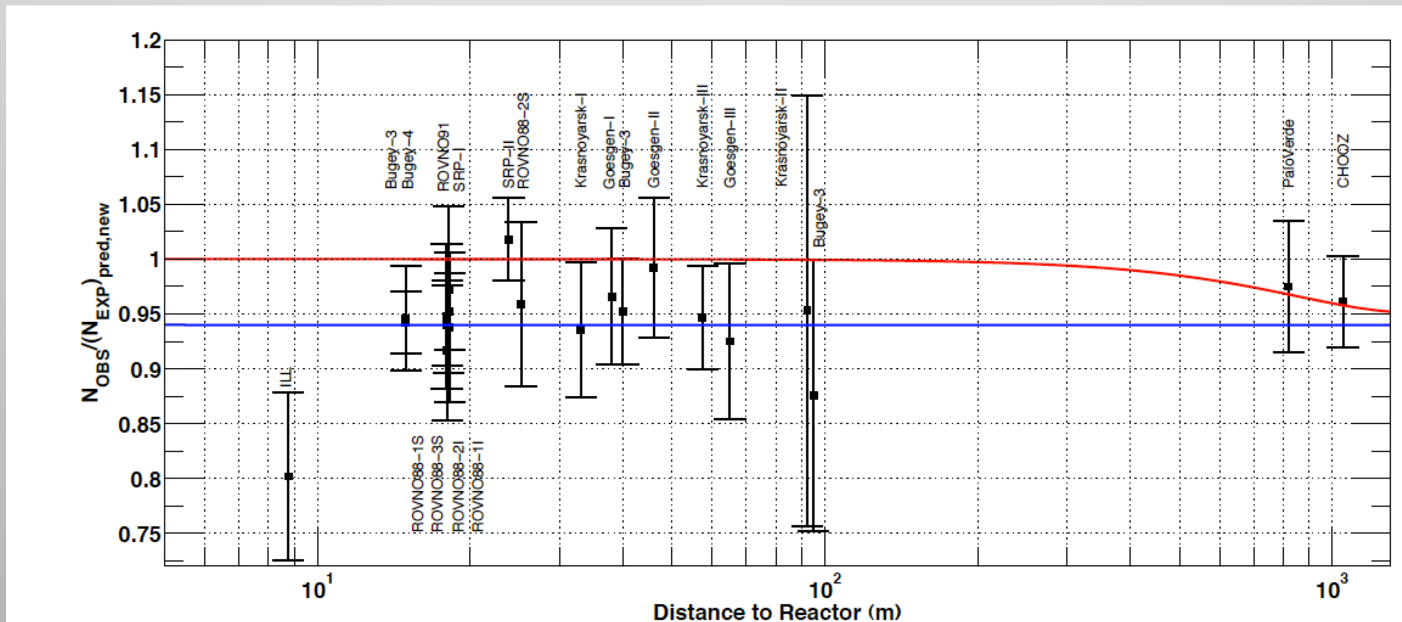
Mueller, et al: arXiv:1101.2663
Huber: arXiv:1106.0687

- But, there are still considerable uncertainties related to some corrections:
  - a high-precision spectral measurement might help

The Reactor Antineutrino Anomaly

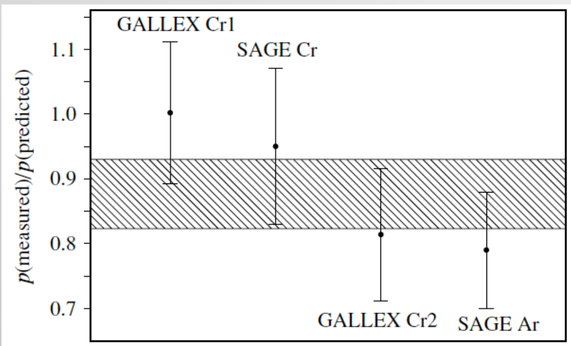
- Mention, et al, re-analyzed many previous short baseline reactor experiments, in light of their new antineutrino flux prediction
- The result: new global "Reactor Antineutrino Anomaly"

$$N_{obs}/N_{pred} = 0.979 +/- 0.029 => 0.943 +/- 0.023$$

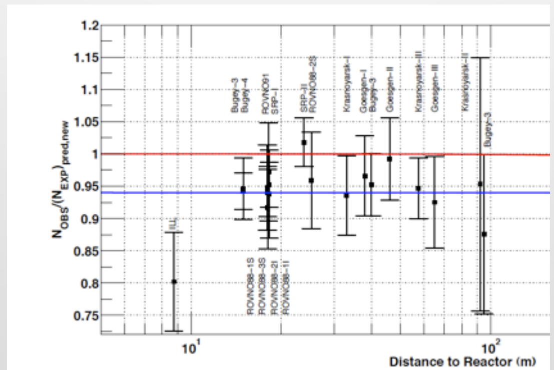


arXiv:1101.2755v4

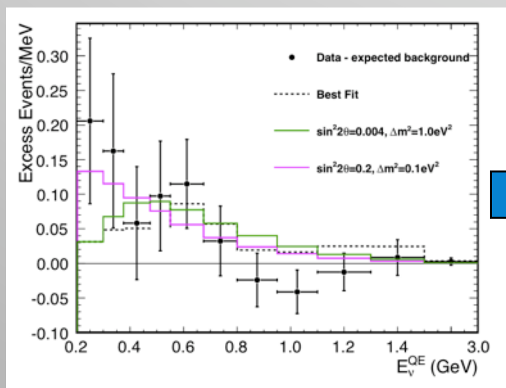
The Reactor Anomaly is consistent with other hints at a sterile flavor



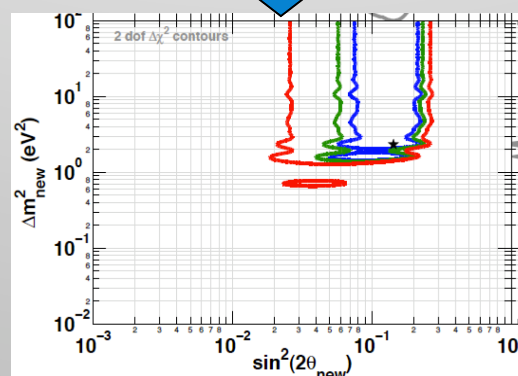
SAGE/GALLEX



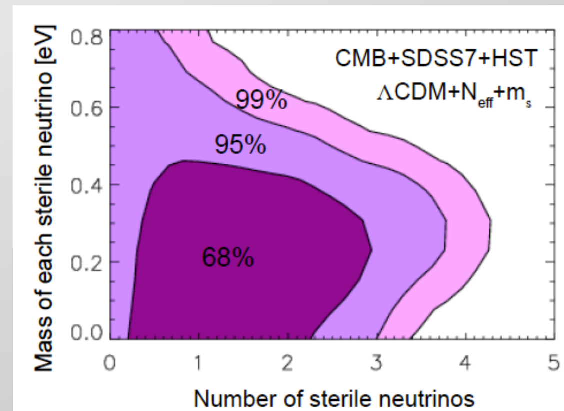
Reactor Anomaly



MiniBOONE



Combined



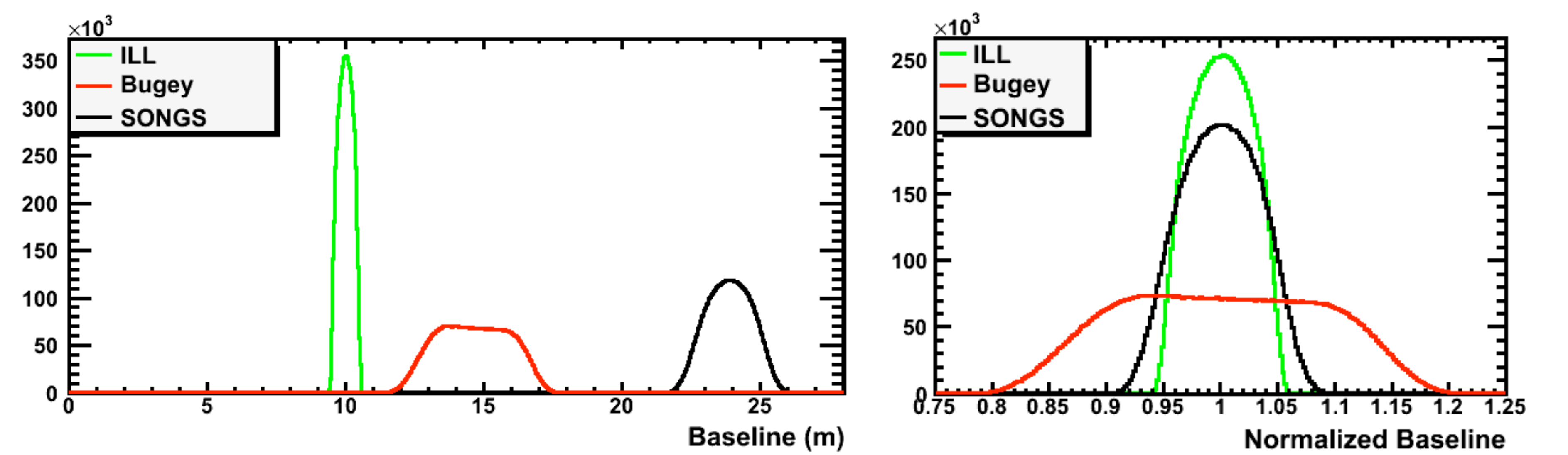
Astrophysical measurements are also consistent with ~eV sterile(s)

The recent results have sparked a new flurry of interest and activity

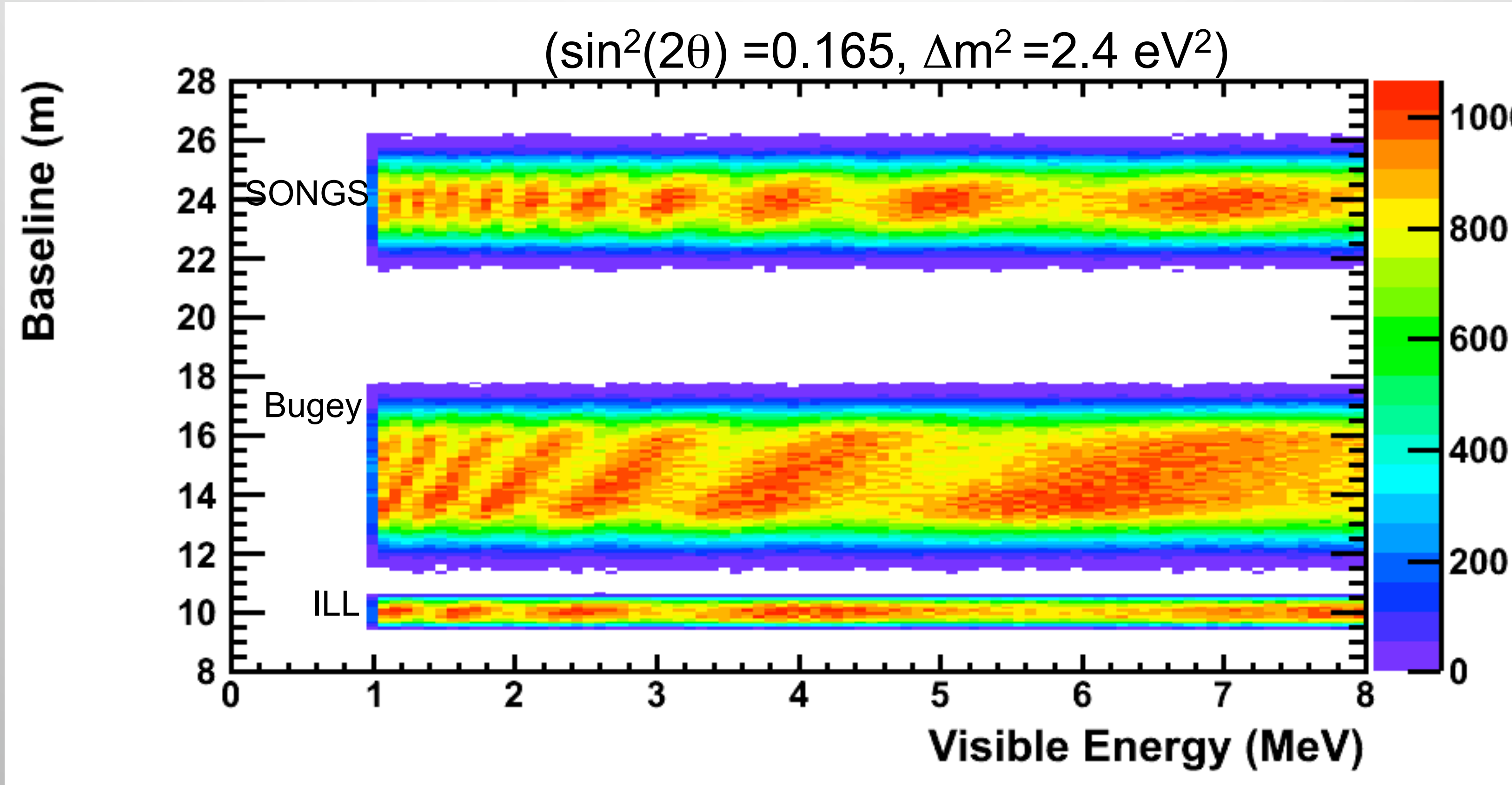
- Most sterile hints take the form of a deficit or excess relative to an (uncertain) expectation
- Strong desire in community for definitive experiments based on measurement of oscillation patterns
- Can a new short baseline reactor experiment help?

At short baselines, a reactor is not a point source

Reactor	Baseline	Core	Detector	ΔL/L (FWHM)	Power	Flux ν/m²/s
ILL	10m	Ø0.4m x 0.2m (HEU)	Ø1mx1m	~8%	58 MW_{th}	~$1x10^{16}$
Bugey3	15m	Ø2.5 x 2.5m	1mx1m	~30%	2800 MW_{th}	~$2x10^{17}$
SONGS	24m	Ø3m x 2m	Ø1mx2m	~10%	3400 MW_{th}	~$1x10^{17}$



Effect of Baseline and Baseline Distribution



- No previous experiment appears to have been optimized in this respect
- Experiments at appropriate small and large reactors would be complementary:
  - efficiently probe different Δm^2 regions
  - measuring flux/spectra from different core compositions

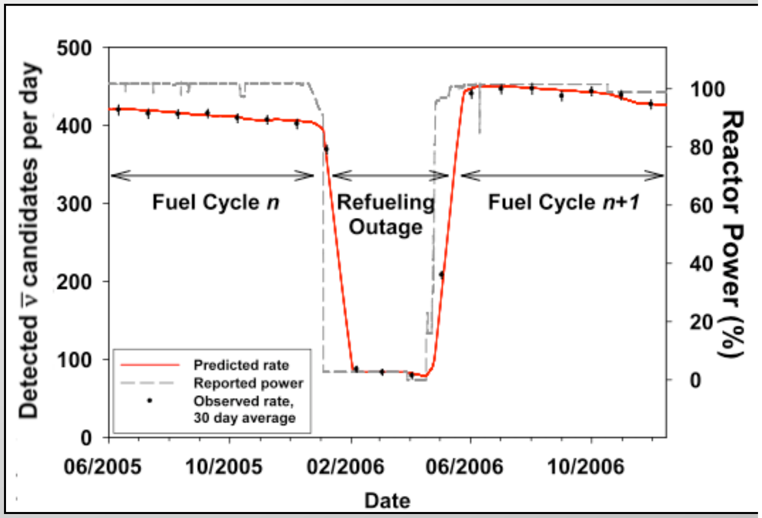
SCRAAM: The Southern California Reactor Antineutrino Anomaly Monitor

- Our proposal is to perform a relatively rapid and inexpensive experimental measurement
  - —Direct sterile oscillation sensitivity via spectra distortion
  - —High statistics flux and spectrum measurement from a single Pressurized Water Reactor (PWR)

- This requires access to location(s) with high antineutrino flux and appropriate core-detector geometry

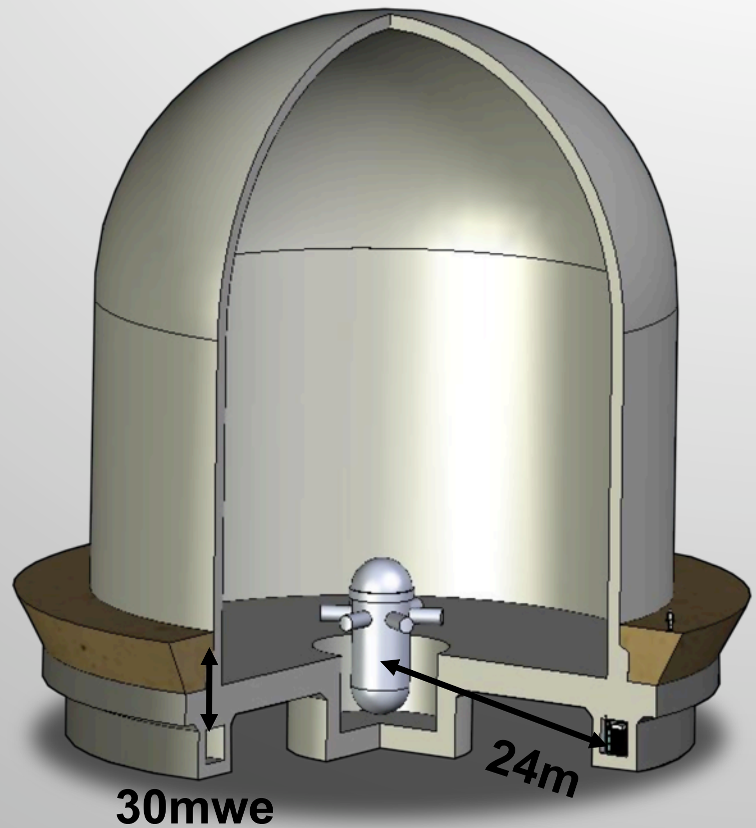
The San Onofre Nuclear Generating Station:
Our (nonproliferation) laboratory for over a decade

Direct Observation of reactor fuel burnup via antineutrino counting



- We have cultivated an exceptionally strong and trusting relationship with SONGS:
  - A multitude of access requests have been readily granted since 1999
  - Provide unescorted reactor access, deployment assistance, commercially sensitive fueling data, introductions to other operators, ...
- We possess unparalleled operational experience in this industrial environment:
  - **Five** detector deployments since 2003

Tendon Galleries are Ideal Deployment Locations

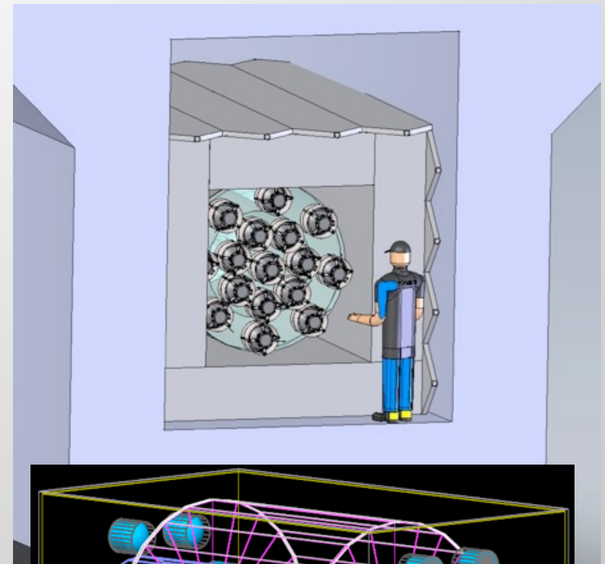


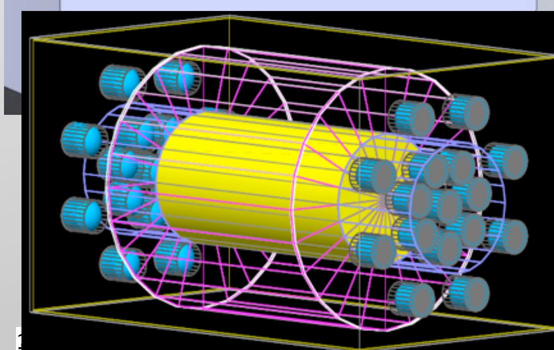
- High Flux: ~10^{17} $\nu/m^2/s$
- 130-180m to other reactor
- Gallery is annular – unfortunately no possibility to vary baseline

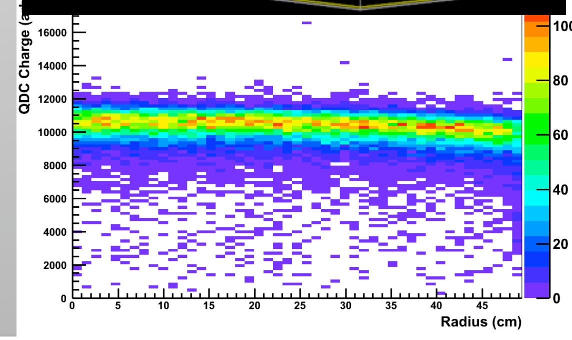
Tendon Gallery Access

The SCRAAM Detector Concept

- A relatively long/narrow geometry is needed: Ø1m x 2m length
  - Tendon gallery is fairly narrow
- 1.5 ton active mass
  - ~9000 inverse beta interactions/day
  - Conservative 40% efficiency gives detection rate of ~4000/day
- Double ended optical readout and diffuse reflective coating for good light collection and position uniformity: expect to achieve 10% energy resolution at 1MeV
- Guide tubes for calibration
- Aim for at least 4% absolute normalization
  - e.g. include partial “gamma catcher” to increase precision and efficiency
- Component costs: ~$800k

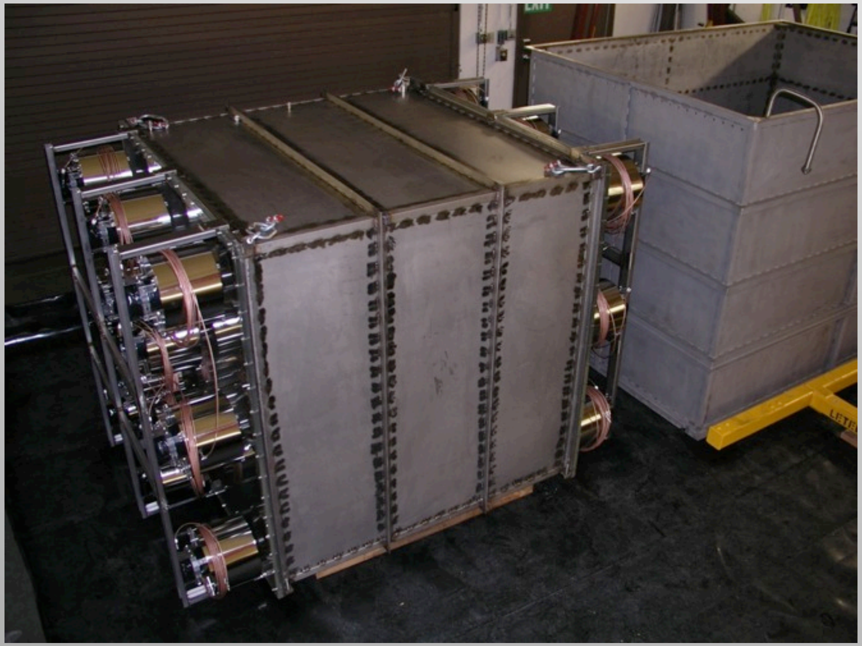


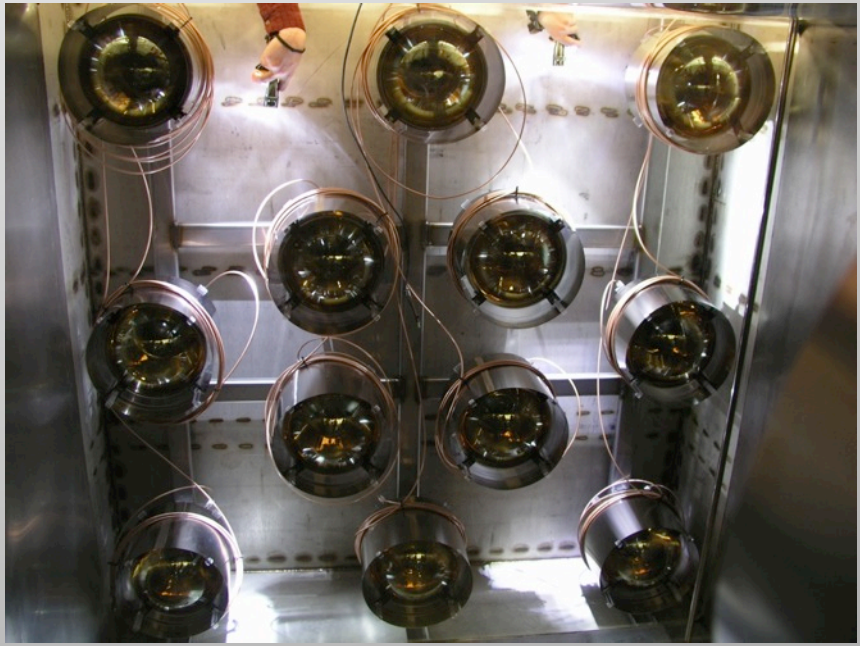




We have completed considerable R&D on detectors of this scale

- Most recent: 3.6 ton liquid scintillator detector (BC-525, 0.1% Gd)
  - For deployment at a CANDU6 reactor in 2012
  - Understand safety and regulatory requirements for reactor site
  - Successful commissioning run just completed
  - Validated mechanical design for double ended PMT readout

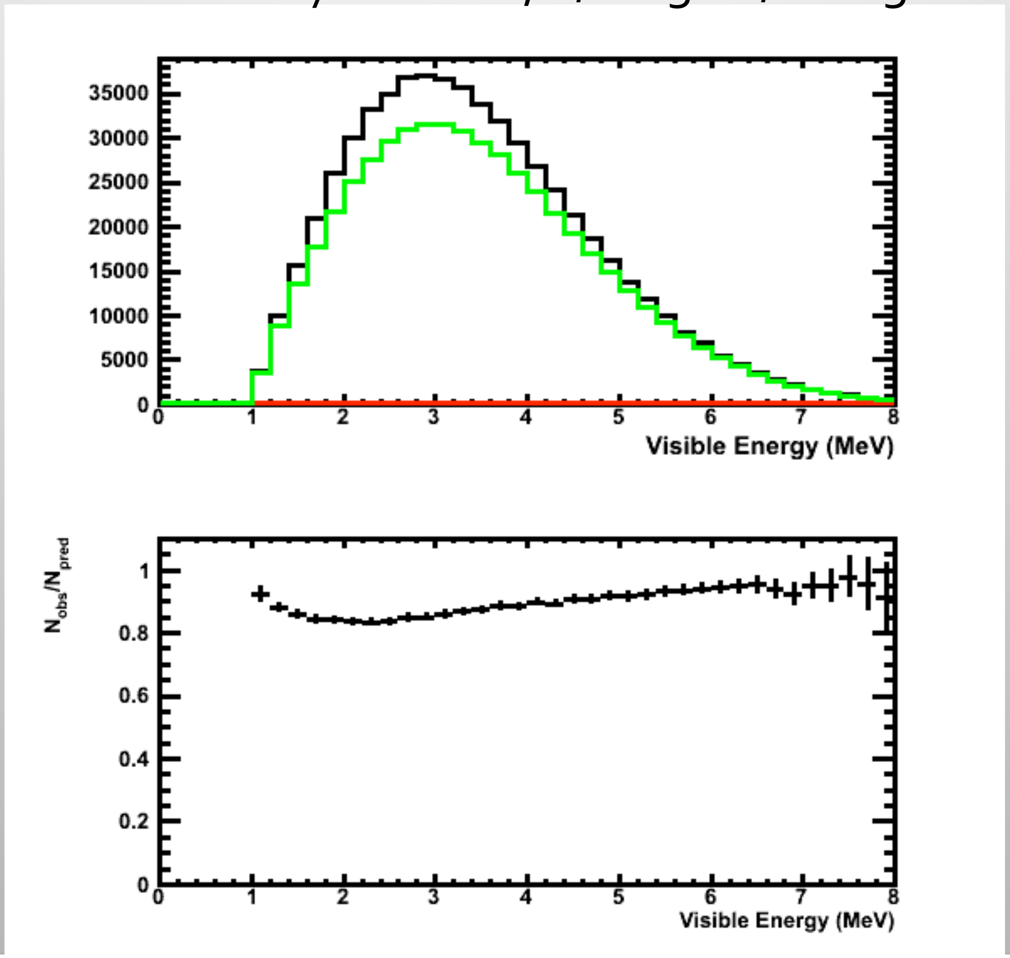




Example Oscillation Patterns:
For SONGS core, spectral sensitivity remains at 24m

150 days, $\sin^2(2\theta) = 0.165$, $\Delta m^2 = 0.15\ eV^2$

1.5% bin-to-bin systematic, 8/1 Signal/Background

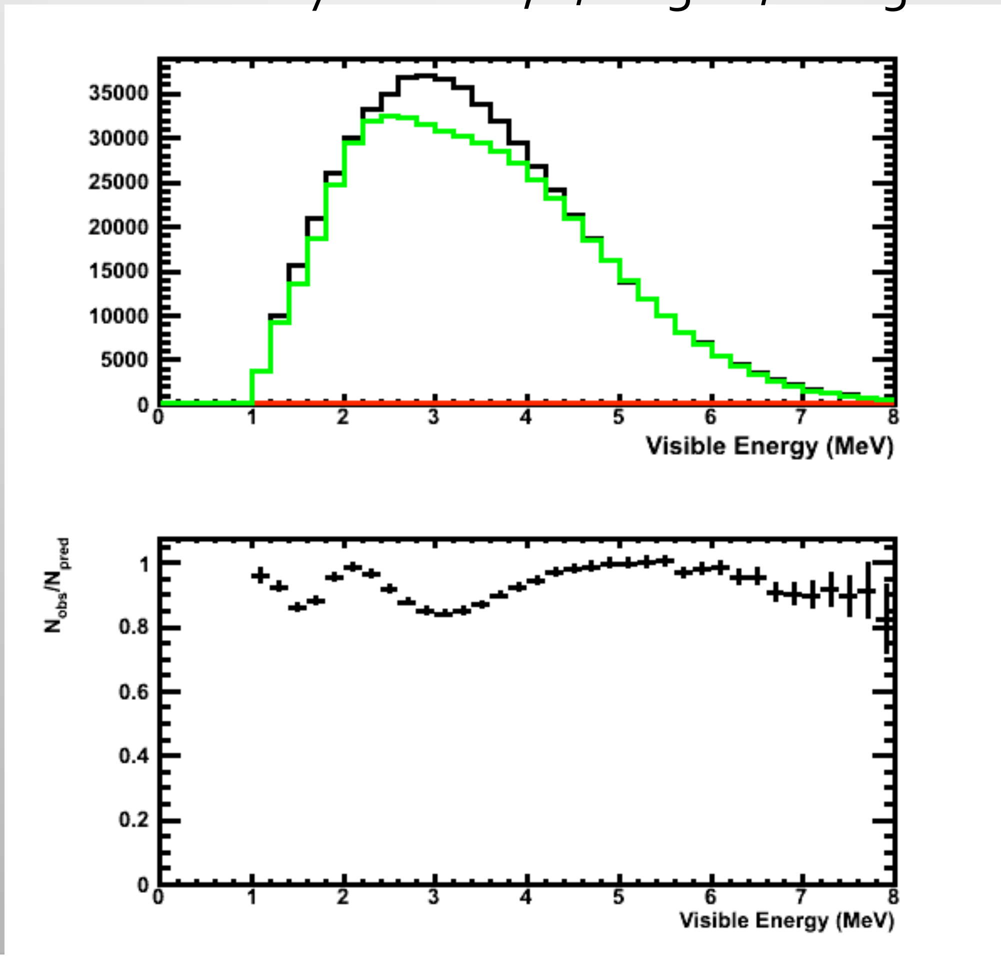


Example Oscillation Patterns:

For SONGS core, spectral sensitivity remains at 24m

150 days, $\sin^2(2\theta) = 0.165$, $\Delta m^2 = 0.60\ eV^2$

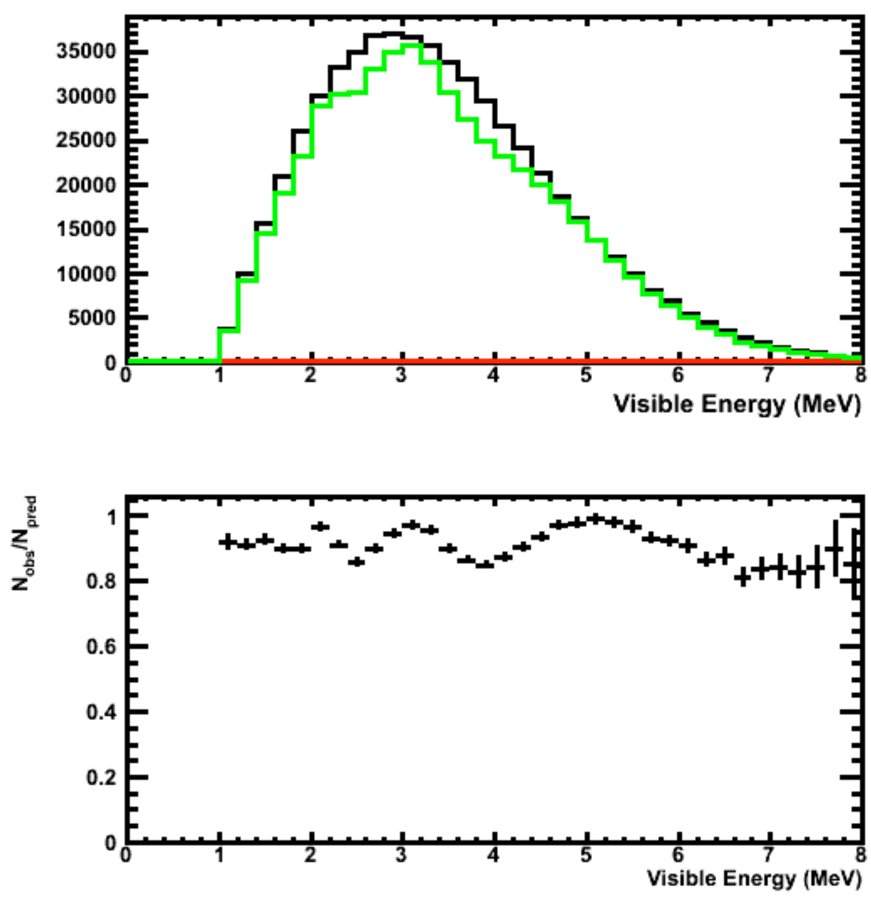
1.5% bin-to-bin systematic, 8/1 Signal/Background



Example Oscillation Patterns:
For SONGS core, spectral sensitivity remains at 24m

150 days, $\sin^2(2\theta) = 0.165$, $\Delta m^2 = 1.2\ eV^2$

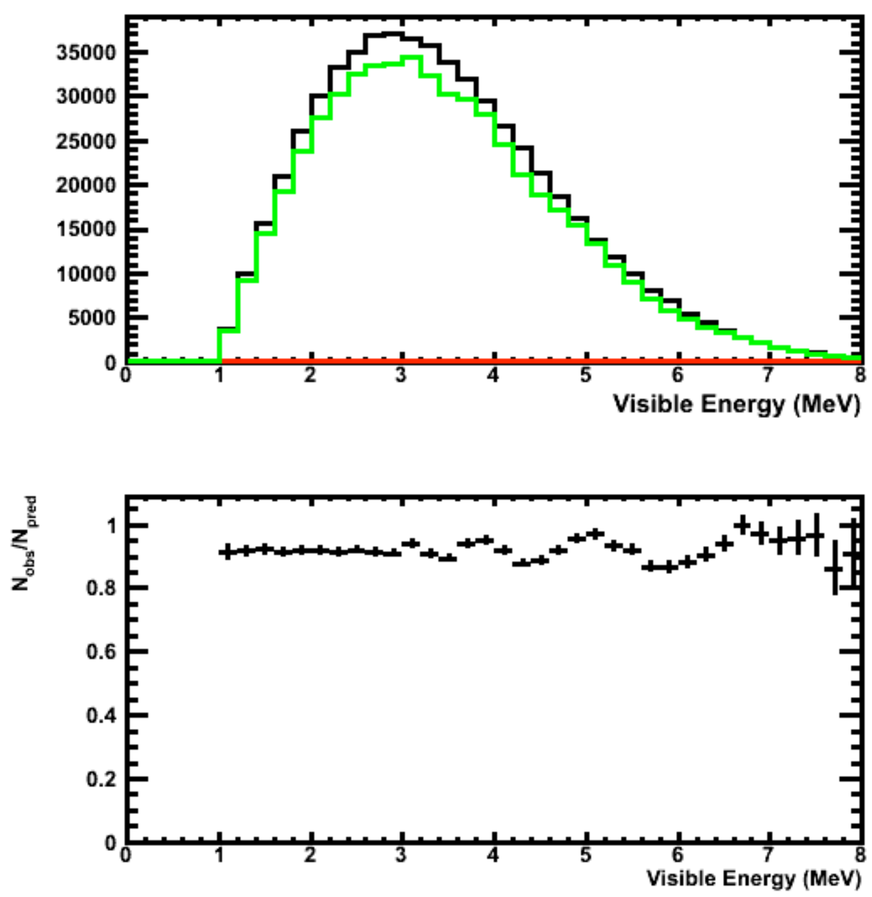
1.5% bin-to-bin systematic, 8/1 Signal/Background



Example Oscillation Patterns:
For SONGS core, spectral sensitivity remains at 24m

150 days, $\sin^2(2\theta) = 0.165$, $\Delta m^2 = 2.4\ eV^2$

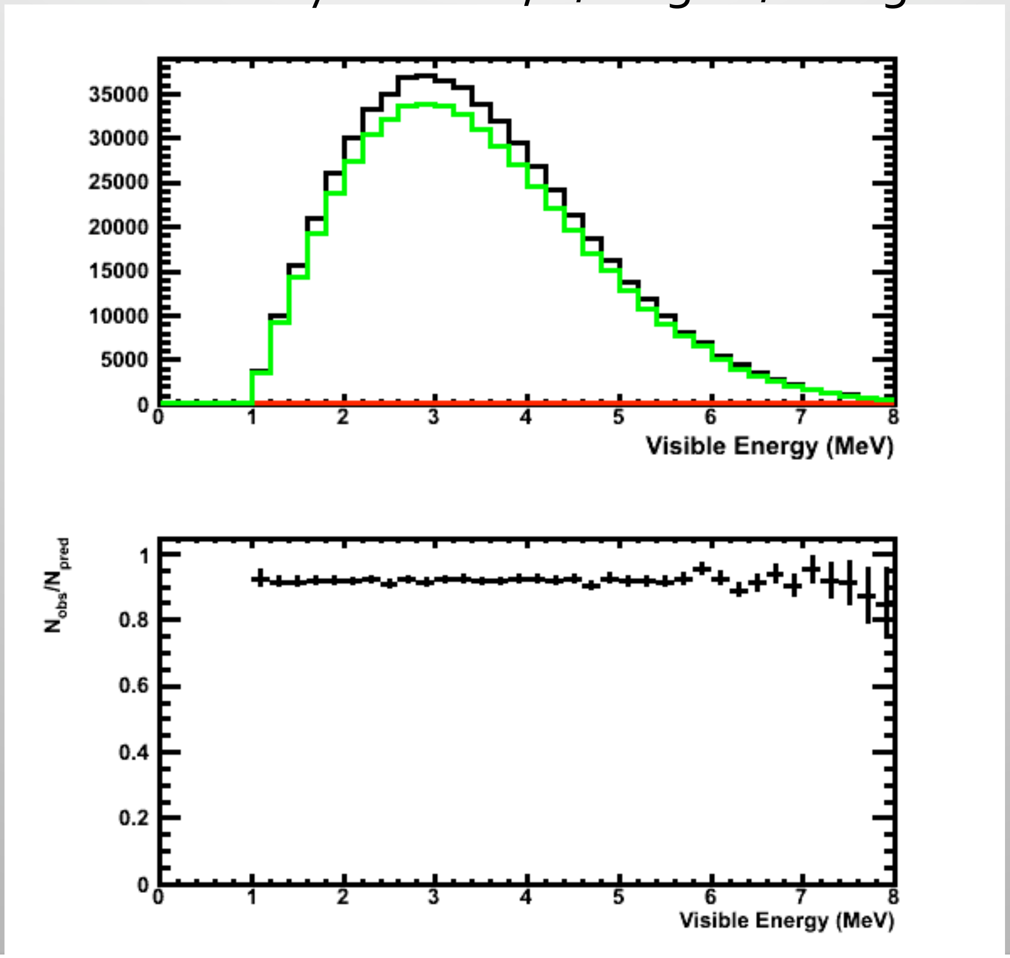
1.5% bin-to-bin systematic, 8/1 Signal/Background



Example Oscillation Patterns:
For SONGS core, spectral sensitivity remains at 24m

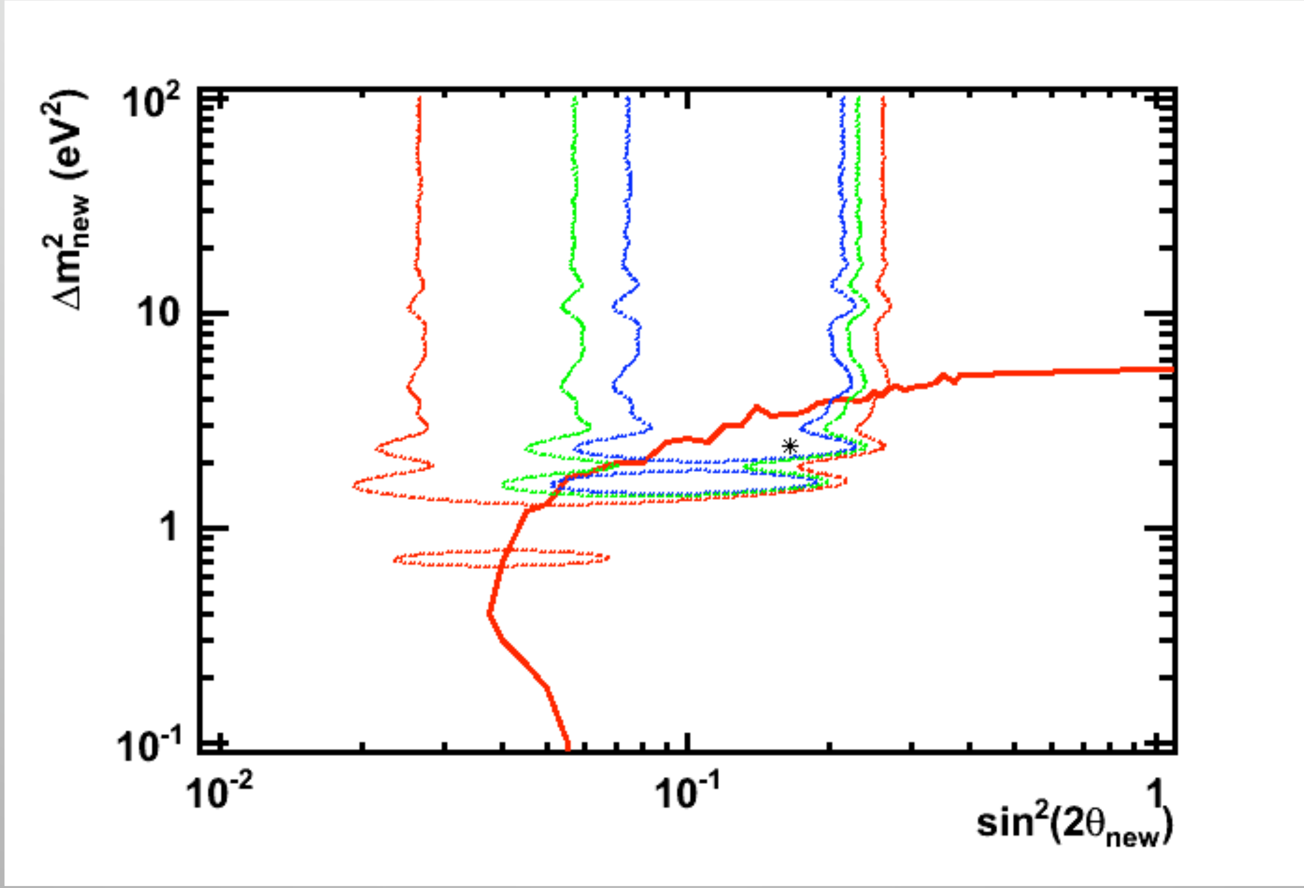
150 days, $\sin^2(2\theta)$ =0.165, Δm^2 =4.8eV^2

1.5% bin-to-bin systematic, 8/1 Signal/Background



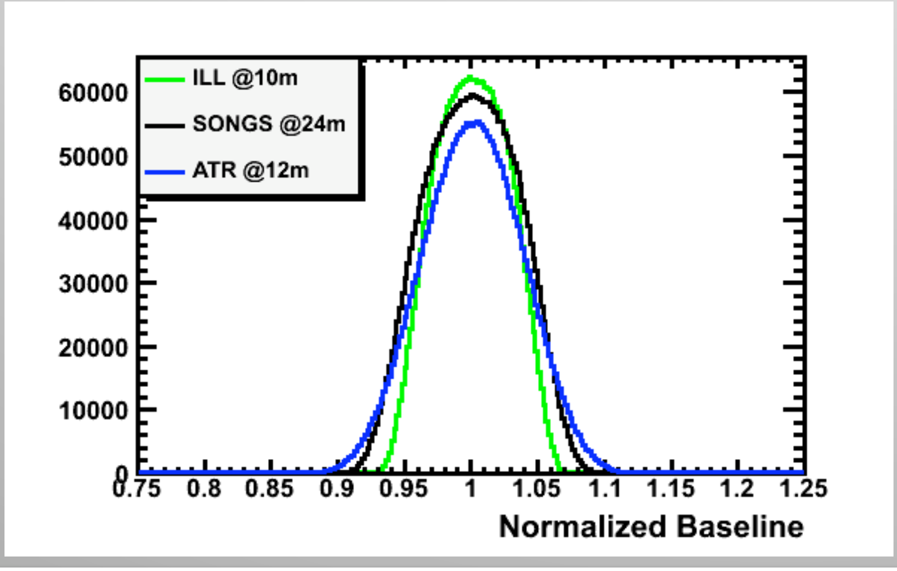
Exclusion Estimates: Shape

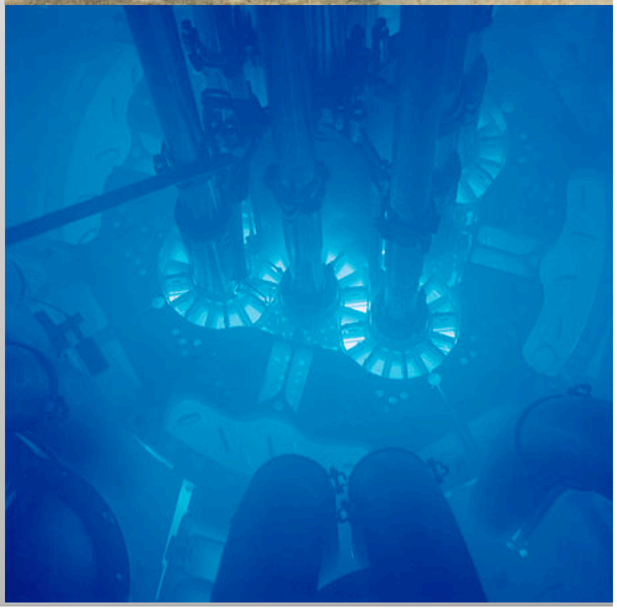
- 150 days, 99% C.L.
- 1.5% Energy scale error, 8/1 Signal/Background



Investigating possibility of complementary compact core measurement

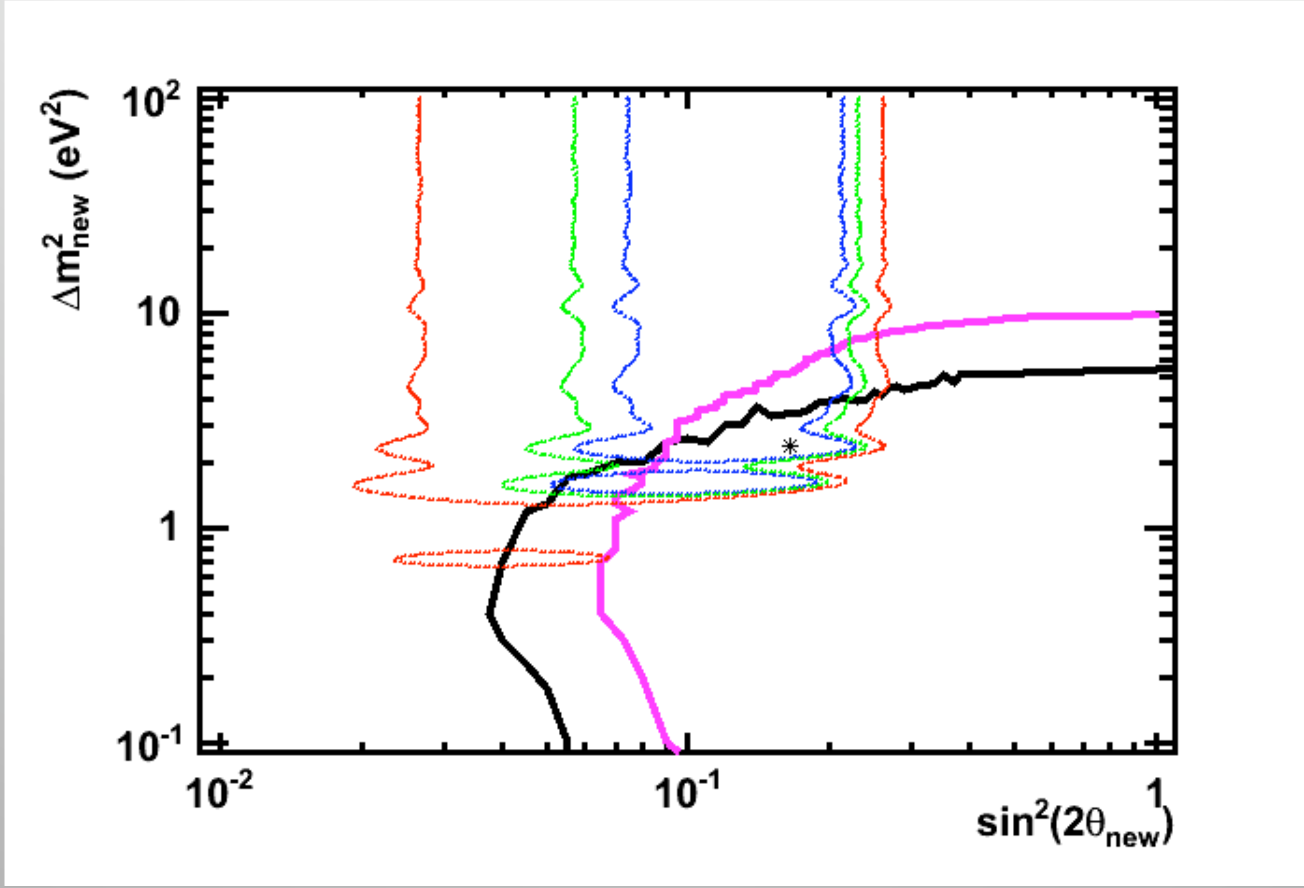
- Advanced Test Reactor at Idaho National Lab
- Unique “serpentine” 1.2m HEU core, ~150MW_{th}
- Convenient 60 day on, 30 day off cycle
- Potential below grade deployment locations near core
- At 12m baseline, spread similar to that at SONGS





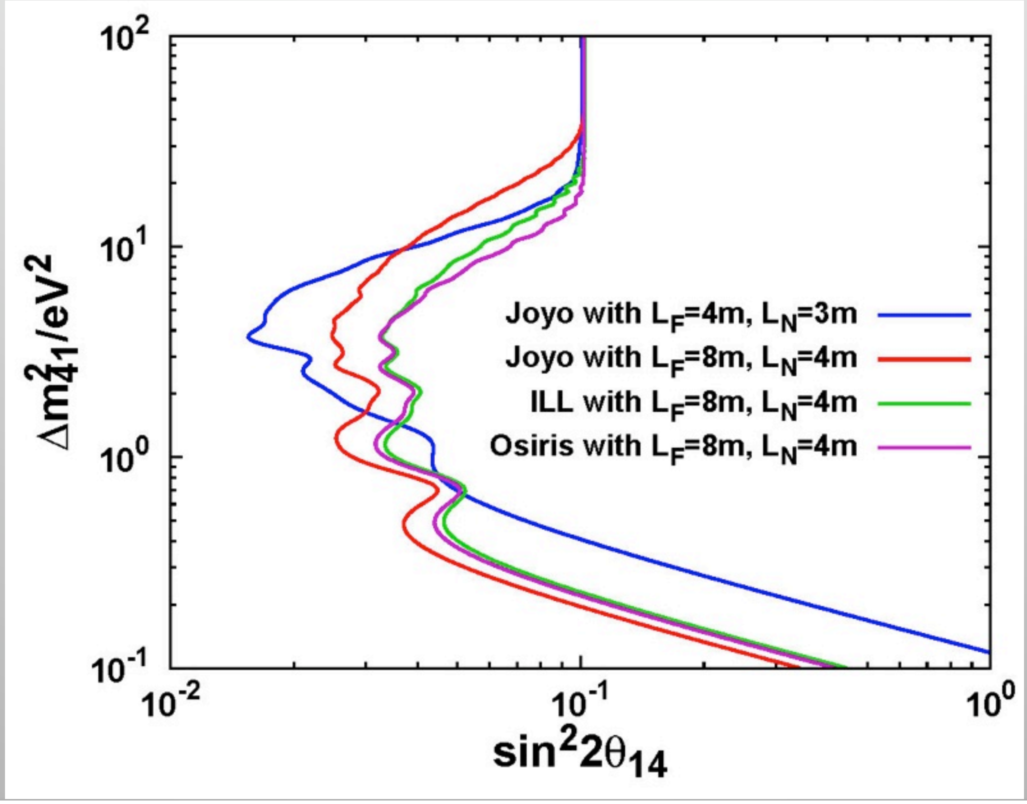
Exclusion Estimates: Shape

- 99% C.L.; 150 days@ SONGS; 300 days @ ATR
- 1.5% Energy scale error, 8/1 Signal/Background



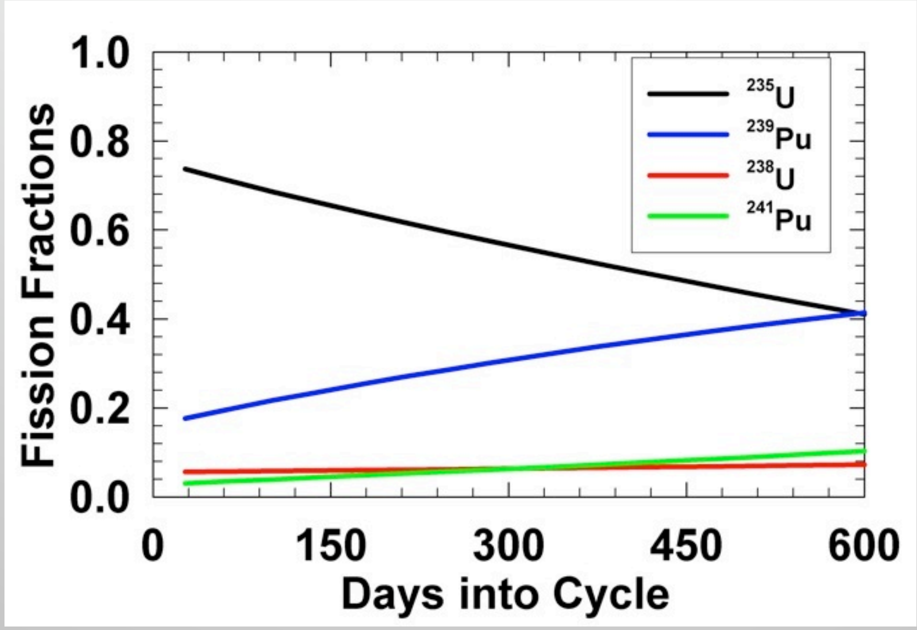
Combined analysis of multiple baselines would have broad sensitivity

- Key parameters would be relative energy scale and normalization: O. Yasuda, arXiv:1107.4766



SONGS Core evolution is well understood

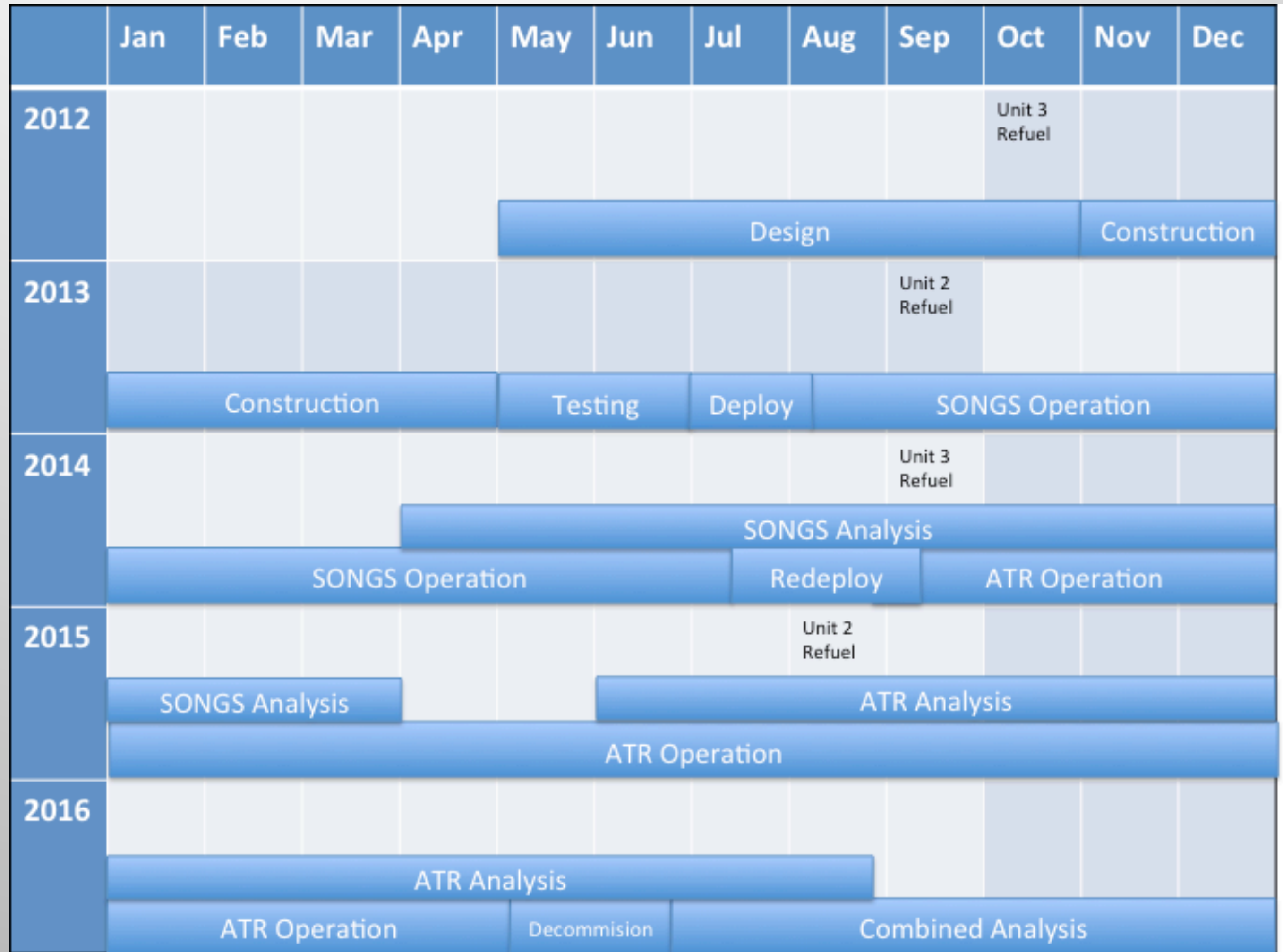
- Again, through our long interaction with SONGS we have access to operator fueling and reactor data



- Unlike the theta13 near detectors, the SCRAAM spectrum measurement would effectively be from a single core
  - In the absence of spectral distortion, this measurement could better constrain prediction uncertainties

Nominal Schedule

- SONGS outages are key; ~50 day background measurement:
  - Unit 2 Sept. '13
  - Unit 3 Sept '14
- Given our recent experience, 15-18 months from design to deployment seems feasible
- Could have first results within ~9 months of data taking



Effort and Budget

	FY12	FY13	FY14	FY15	FY16
PI	0.5 FTE	0.5 FTE	0.75 FTE	0.75 FTE	0.75 FTE
Post-doc	0.5 FTE	0.5 FTE	0.75 FTE	0.75 FTE	0.75 FTE
Engineer/ Technologist	0.66 FTE	0.33 FTE	0.17 FTE	0.17 FTE	0.08 FTE
Total FTE	1.66 FTE	1.33 FTE	1.67 FTE	1.67 FTE	1.58 FTE
Equipment	$350K	$440K			
Approx. Total Cost	$900K	$900K	$500K	$500K	$500K

Potential Collaborators

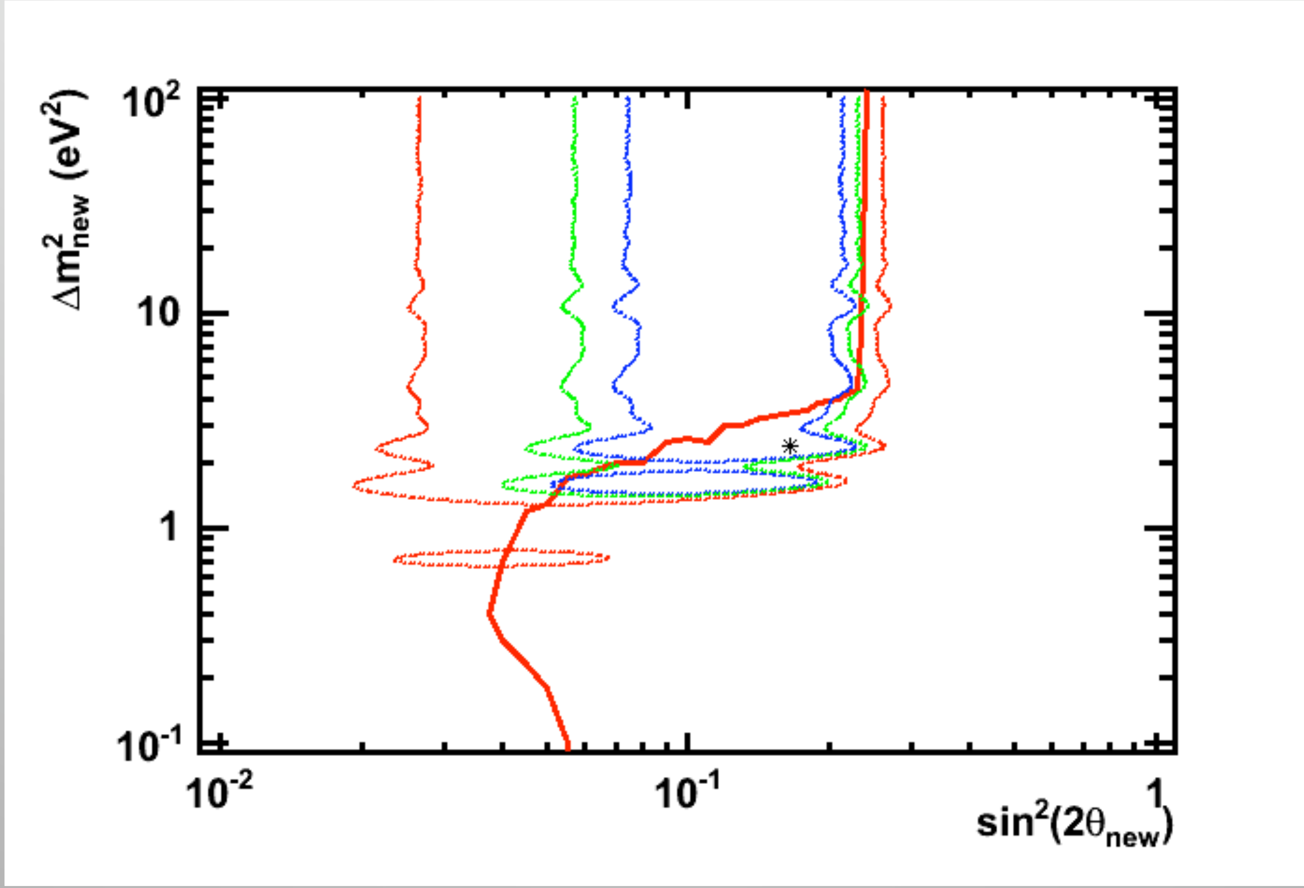
- John Learned, U. Hawaii
  - Fabrication, software
- HANARO Group (South Korea)
  - High flash-point Scintillator
- …

Conclusions

- Short baseline reactor efforts have continued, attempting to develop a new safeguards technique
  - The reactor access, reactor simulation, and detector design expertise from the applied community can be exploited to probe the "RAA"
- Short baseline measurements at appropriate small (research) and large (power) reactors would be complementary:
  - Efficiently probe different Δm^2 regions and measuring spectra from different core compositions
  - SONGS appears optimal for a power reactor deployment
  - ATR appears very promising as a research reactor deployment site
  - Combined analysis of two deployments could have even better sensitivity
- SCRAAM would rapidly exclude a large fraction of the ~ $1eV^2$ "RAA" allowed phase space, and have good discovery potential in the "best-fit" region

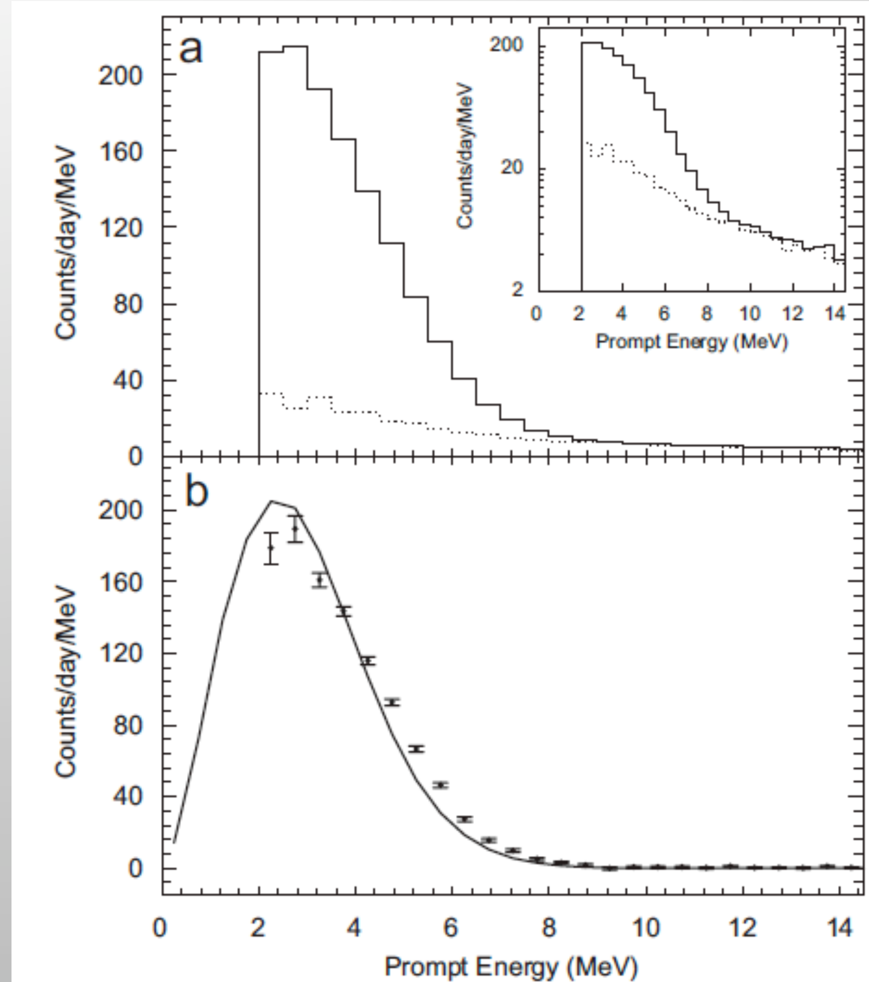
Exclusion Estimates: Shape + Rate

- 150 days, 99% C.L.
- 4% Normalization, 1.5% Energy scale error, 8/1 Signal/Background



SONGS Backgrounds

- Our SONGS1 detector had S/B of ~4/1
- Background was primarily:
  - Fast neutron recoil followed by capture
  - Multiple neutron capture
- There is reason to believe that we can do considerably better with SCRAAM:
  - SONGS1 had only 95% muon veto and "non-hermetic" shielding
  - Improved neutron capture efficiency and analysis will allow rejection many more multiple neutrons



Detection Rate, Detector Systematics

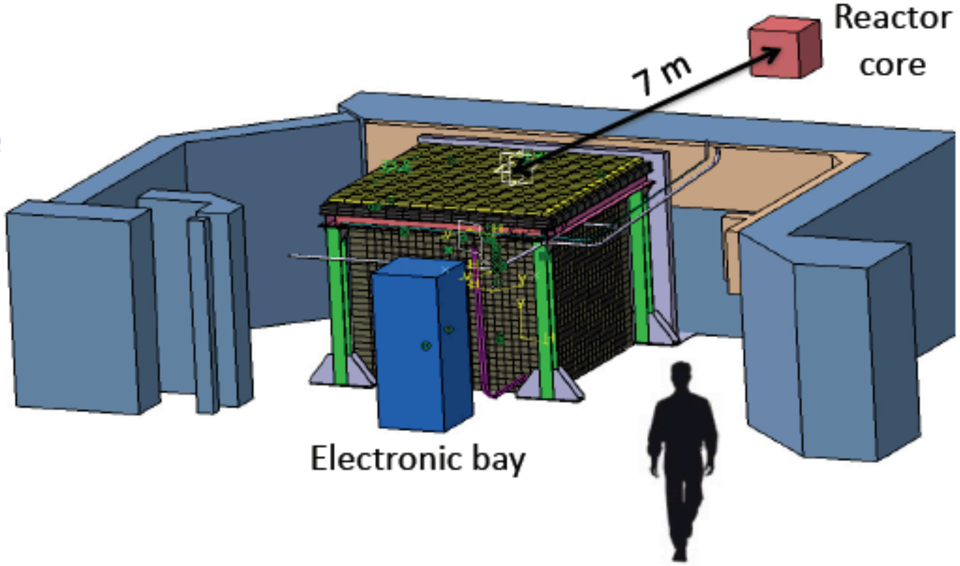
- Assuming 40% efficiency, expect detection rate of about 4000 ν/day
- Precision on absolute efficiency of ~ 4% would require considerable effort, but appears feasible
- Extensive source calibrations would be required

Systematic	Target Value	Mitigation
No. of target protons	1.5%	Weighting, solvent selection
Neutron efficiency	1.5%	Gamma catcher, calibration
Positron efficiency	1%	calibration, ideally ≈ 500 keV threshold
Core-Detector distance	0.5%	Through document review, possible survey
Deadtime	0.25%	precise measurement, tracking
Detector Total (Flux Measurement)	2.4%	
Reactor Systematics	2.7%	
Total on N_{obs}/N_{pred}	3.6%	

A compact core effort: Nucifer
(see also Y.D. Kim poster)

Nucifer @ Osiris

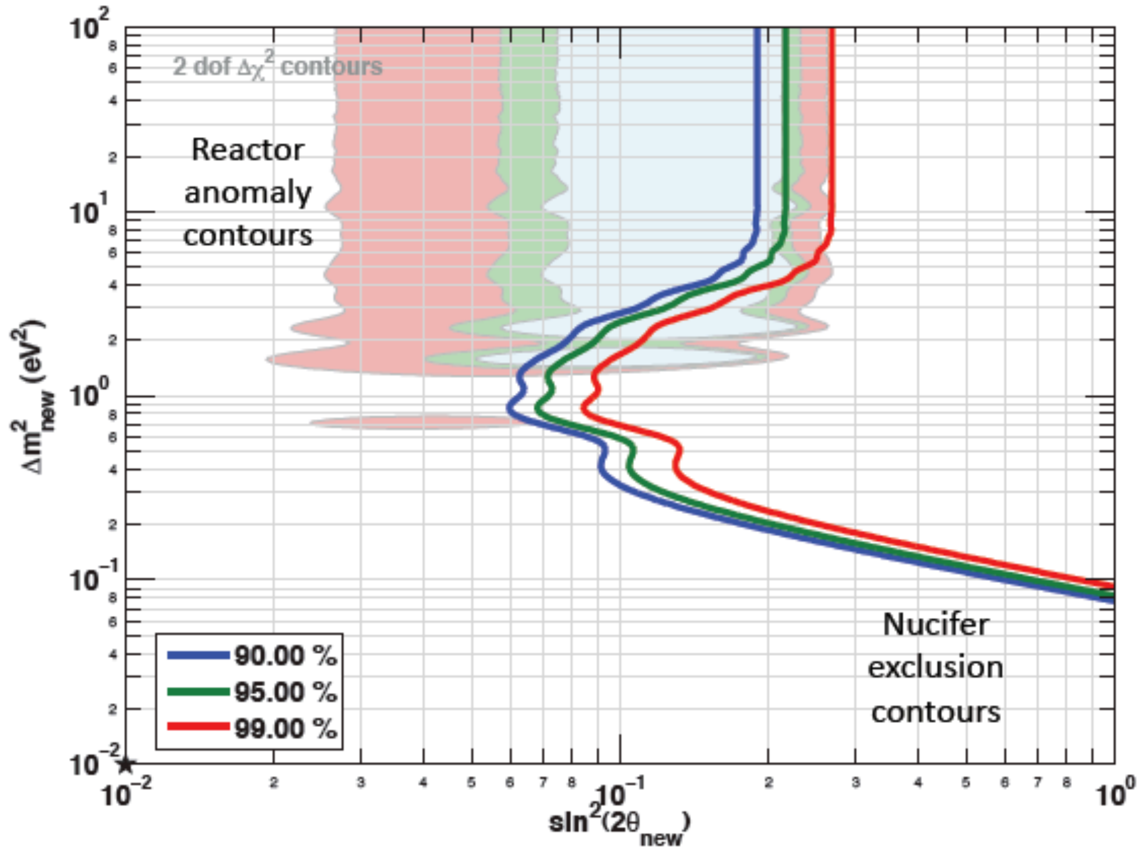
- 70 MW reactor
- Nucifer 7 m from the core
- 15 mwe overburden



650 ν/day expected
Assuming 50% det efficiency

- **Reactor Background:**
  - Additional 10 cm lead shielding needed due to reactor induced γ rays
- **Based on simulation and on site measurements:**
  - $S/B_{accidentals} = 1$
  - $S/B_{correlated} = 0.25$ before PSD cut, ~2.5 expected after PSD selection. Reactor OFF 33% of the time, will allow final background subtraction.

Testing the 4th ν hypothesis



100 days full power @ Osiris:

- 4% norm error
- E resol = 0.15*E
- 2% E scale error
- S/B = 1 (?), assuming same shapes (worst case).

Other Proposed Efforts ($$$)

- PBq neutrino sources into KamLAND, SNO+, etc
- Multi-Detector Accelerator experiments
  - BOONE
  - 2 x LAr TPC @ CERN PS
  - 2 x LAr TPC @ FermiLAB
- (PLANCK will provide much tighter cosmological bounds in ~2014-15)